

# **AUV Self Noise Control and Acoustic Signature Measurements**

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## **LONG-TERM GOAL**

The long-term goals of this project are to develop techniques, which can be used in the design of AUV's to minimize the radiated noise. The self noise from an AUV can interfere with acoustic sensors on board the AUV, specifically acoustic modem sensors and other sonar equipment. Hence the reduction of AUV noise and structural vibration is essential in increasing the reliability of operation of the on-board acoustic sensors.

## **OBJECTIVES**

In achieving the long-term goals of this project, the results of numerical models used in the prediction of the radiated noise have to be verified using acoustic signature field measurements. However, open water measurements are difficult to achieve because of the logistics and therefore schemes to measure the AUV acoustic signature in the lab are explored and compared to open water measurements. Additionally, lab acoustic signature measurements would have the advantage that modifications can be readily tested to assess the impact of the modifications on the radiated noise. The objectives of this project can be summarized as follows:

- (a) Measure and compare the noise signature of an Ocean Explorer Class AUV using a reverberation tank approach and a free field open water approach.
- (b) Characterize the noise signature through measurement and modeling.
- (c) Provide general recommendation as to how the noise signature can be reduced.
- (d) Develop a prediction model for noise signature, which can be used in future AUV designs.

## **APPROACH**

The initial emphasis of this project has been in performing measurements of the acoustic source levels of existing, Ocean Explorer class, AUV's. One of the objectives of this project is to perform most of the acoustic signature measurements using a reverberant tank. The tank is readily available making such measurements easier to obtain. Thus, the first task of the project was to qualify the reverberant tank, and establish a procedure to obtain overall sound power levels from which acoustic source levels could be determined.

For the purpose of qualifying the tank a J9 reference acoustic source was used. The J9 was located in a corner of the test tank and sound pressure level measurements performed at nine

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locations located in the reverberant field. The nine measurements are required for spatial averaging. The spatial and frequency (one-third octave frequency bands) averaged sound pressure levels were then multiplied with the tank constant based on the tank acoustic absorption characteristics. The tank acoustic absorption characteristics were obtained through reverberation time measurements. The radiated sound power was thus computed for the J9. From the computed sound power a source level was determined and compared to the level specified for the J9. The computed and specified source levels for the J9 matched to within  $\pm 2$  dB. This qualified the test tank for use to perform source level measurements for the AUV.

For the AUV source level measurements, the AUV was held stationary in the same location as the J9. The AUV was held stationary by removing its propeller. Thus, the initial source levels measured were for the AUV without the propeller. Comparison of these initial measurements to other measurements where the AUV still had the propeller on would be required to obtain a measure of the propeller contribution. For this purpose the measured reverberant tank source levels were compared to the source levels measured for the same AUV's in the NUWC anechoic tank. In a previous study [1] on the same class AUV's, acoustic signature measurements were performed in the NUWC anechoic tank.

Apart from the reverberant and anechoic signature measurements, a measure of the acoustic source levels with the AUV under power, in open water, were considered necessary. For this purpose, open water measurements were scheduled at the South Florida Test Facility (SFTF). This site was selected because of its close proximity, and hence the logistics of performing the acoustic signature tests were reasonable. The disadvantage of this facility is that it is located in an area where the background noise levels are relatively high. The open water measurements, apart from providing a measure of the source levels could also provide directivity patterns for the radiated noise. It turned out that the SFTF was too noisy for directivity measurements, however some limited source levels measurements were achieved. The main lessons learned from these measurements was more related to the AUV support requirements, especially in monitoring the AUV trajectory at the peak signature levels to determine the distance of the AUV from the measuring hydrophone. Since the acoustic results of these measurements were limited, open water measurements in a low background noise facility are scheduled for the future.

To determine the influence of changes in the AUV design, that were ongoing parallel to performing the acoustic signature measurements, test tank source levels and structural vibration measurements were performed on new AUV components to identify significant acoustic sources. The AUV propulsion system is currently being redesigned and supporting the noise control effort of the redesign was considered important. While this was not explicitly part of the original proposal objectives, contributing to improvements in the design from an acoustic signature viewpoint was considered a priority. This task ended up taking some precedence on the modeling portion of the work.

The numerical modeling of AUV structure and acoustic environment for the prediction of acoustic signature is based on building a finite element (FE) boundary element model. The first task that had to be performed was to obtain the material characteristics of some of the AUV structure components, which are not fabricated from standard catalogued material. Specifically, material characteristics of the fiberglass outside shell are unknown. For this purpose, vibration mode measurements were performed on a section of the fiberglass shell. The same section was also modeled using FE, with an arbitrary selection of the moduli of elasticity. The measured frequencies and mode shapes were then compared to the predicted modal frequencies and mode

shapes obtained from the FE model. The elastic moduli used in the FE model were adjusted until matching was obtained. Having obtained this information, a complete shell is being modeled and the estimated acoustic radiation for an input load will be compared to measured levels using the test tank. The approach to be used is to build the FE model in components and test each component addition to with experimental results.

## WORK COMPLETED

The work that has been completed thus far include:

- Reverberation tank qualification tests, including the measurement of the reverberation times to obtain the test tank constants. The measured and reference source level for the J9 compare favorably.
- Sound source level measurements of the AUV without a propeller at rotational speeds corresponding to 4 knots, and the comparison of these measured source levels to the source levels measured in the NUWC anechoic tank.
- Open water offshore signature measurements in 60 feet of water using the SFTF facility of NSWC-CD in Ft. Lauderdale Florida.
- Test tank measurements of the source level and vibration levels of various components of the new AUV propulsion system design, leading to modifications of the new design to reduce the signature levels.
- FE modeling of a section of the AUV from which the elastic moduli have been determined.

## RESULTS

The results for the source level measurements completed thus far are summarized in figure (1).

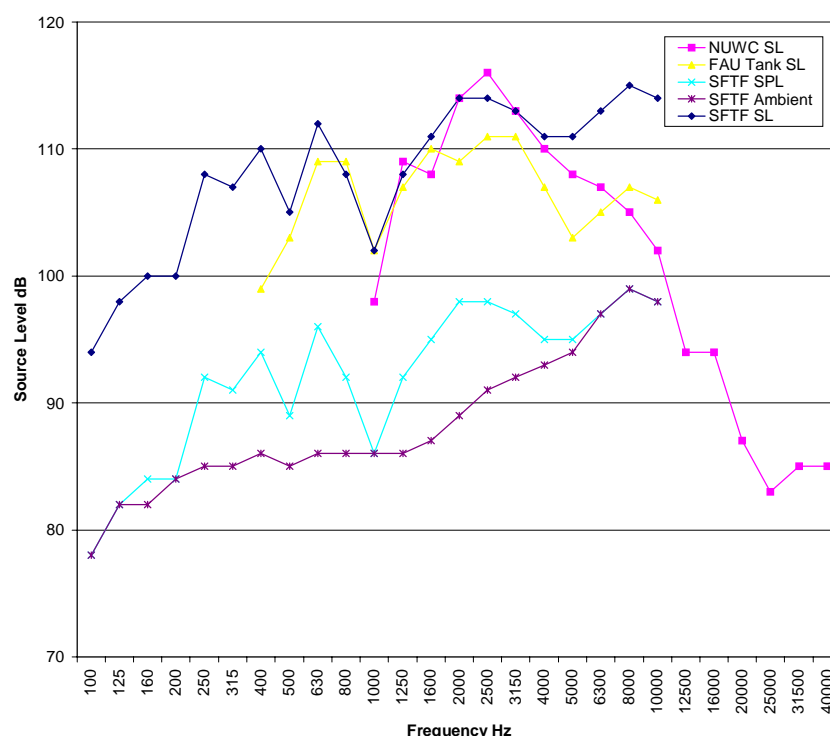


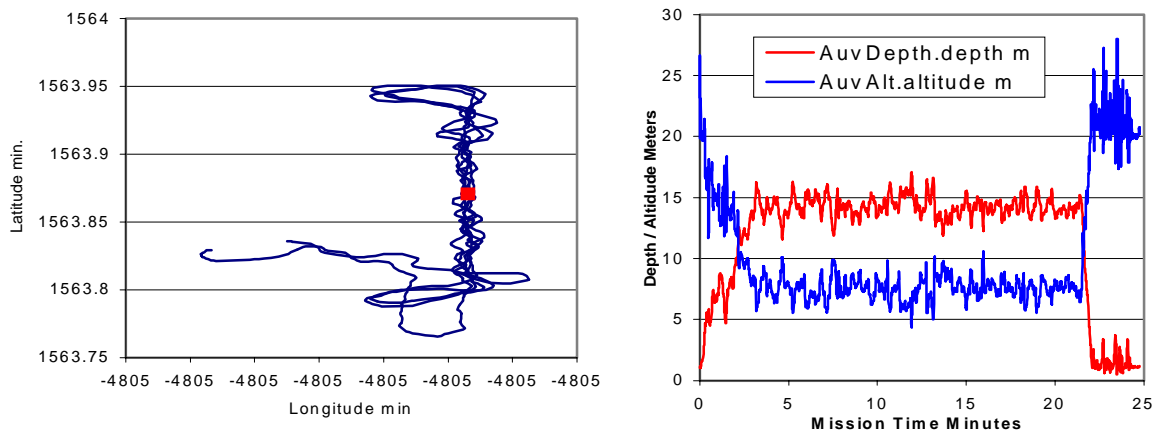
Figure 1. Source Level measurements of AUV.

Shown in figure (1) are:

- (a) the NUWC results previously obtained [1];
- (b) the reverberant tank results with the AUV without a propeller;
- (c) the open water results obtained at the SFTF.

Also shown in figure (1) are the peak sound pressure levels measured in open water as the vehicle approach the hydrophone, and the background ambient sound pressure levels. This data gives an indication of the limitations of the measurements due to the high background ambient levels. The source level was determined by taking into consideration the distance of the AUV from the hydrophone. This required the measurement of the AUV trajectory. Shown in figure (2) is the measured AUV trajectory by the on-board navigation and depth sensors. From this data it is estimated that the AUV was approximately 7 meters from the hydrophone at its closest position. This distance is used to estimate the source level.

Because of the high background ambient sound levels, it was necessary to fly the AUV as close as possible to the hydrophone. The test plan specified a desired distance of 3 meters between the AUV and the hydrophone at its closest position. As can be observed from figure (2), maintaining accuracy in depth and location to within a couple of meters was difficult. Furthermore, these tracks are accurate to within 5 to 10 meters. A change of five meters, when the desired or measured distance between AUV and hydrophone is 3 meters can make a significant difference in the calculated source level. Additionally, the data shown in figure (2) do not include drifts due to current or other external sources, since this data is collected by the AUV on-board sensors.



**Figure 2 AUV Latitude and Longitude tracks and depth during open water measurements. The red dot indicates the hydrophone location.**

Comparing the different results obtained for the acoustic source level of the AUV, there is generally good agreement. The reverberant test tank estimate matches favorably with the measurements performed in the anechoic test tank at NUWC and with the open water measurements. Thus, measurements in the reverberant test tank can be used to be reliably test different AUV configurations and assess the impact on the source level from the differences in

the configurations.

While agreement between reverberant test tank measurements and open water measurements is good (figure 1), the aim is to acquire source level information up to frequencies in the 40 KHz region. It is not possible to acquire data in the 40 KHz frequency range at the SFTF site in Ft. Lauderdale because of the high background noise levels. Furthermore, it would be useful to possibly obtain some directivity measurement of the signature. For these reasons, more open water measurements are scheduled for the near future at a more quiet facility, using one of the newer generations AUV's.

Measurements on the new propulsion section of the AUV, which consists of a direct drive motor, revealed some interesting features. The new design includes vibration isolation mounts between the podule (module containing propulsion motor and control surfaces – dive and rudder – servos) and the remainder of the AUV structure. In one configuration, vibration isolation was also included between the drive shafts and the rest of the vehicle structure. The measurements were performed under various conditions of operation. Some of the initial results from these measurements showed that the new design, which was expected to be much quieter than existing design, which uses a gearbox instead of a direct drive, is actually noisier, by about 10 dB. Furthermore, the source level significantly increases when the propeller was attached. This led to more detailed measurements, especially directed towards understanding the benefits of the vibration isolation. Some modifications have since been implemented in the design which are currently being tested and which look (sound!) promising.

## **IMPACT/APPLICATION**

The long-term impact of this work will be the development of tools that can aid in the design of quiet (low acoustic signature) AUV's. With this tool, the radiated noise from the AUV can be reduced to have minimal, if any, impact on the AUV acoustic sensors, such as acoustic modems and other sonar systems. The short-term impact is the better understanding of the mechanisms generating the radiated noise on present AUV designs and the support of ongoing AUV design efforts to minimize the radiated noise.

## **TRANSITIONS**

No transition of this technology has yet occurred, however, very close collaboration has been established with the FAU AUV design team assisting them in designing the propulsion system for the new version of the AUV to minimize the radiated noise.

## **RELATED PROJECTS**

The projects which are most closely related to this project are: the AUV design and operations at FAU with Dr. Smith as the principal investigator, the acoustic communication project at FAU with Dr. LeBlanc as the principal investigator and the ACOMMS project at NUWC with Dr. Catipovic as the principal investigator. The relationship to these projects mainly stems from providing the test support to measure AUV source levels, as well as providing assistance in the design of AUV components to meet or exceed accepted noise control practice.

## **REFERENCES**

1. "Radiated (and Self Noise) Acoustic Evaluation of FAU's Ocean Explorer", Oasis Inc. Report 1997.